NORTH DAKOTA STATE UNIVERSITY

Tornado Machine

Technical Report

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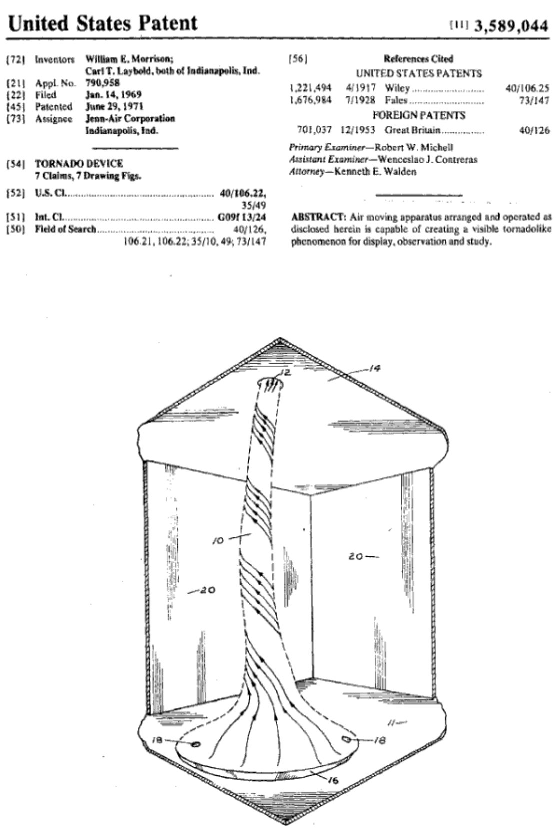
Introduction:

The tornado machine is a tool the Dr. Akyuz uses to demonstrate meteorological events to his and local elementary students. This project was suggested both by Dr. Akyuz and Dr. Green to help Dr. Akyuz with different problems that he has with his current machine. We are looking to make the new machine to have greater portability along with greater functions by giving it more effects that can be used in teaching.

Previous Work:

Currently Dr. Akyuz is using a common basic design for his "tornado machine". The design consists of a metal base with a hole to place a water pan under which is placed a hot plate. On top of the base are four metal columns and four clear plastic panels. The columns are attached to a metal cover in which a fan sits. The plastic panels are set in tracks that allow them to be adjusted. The device is powered by an outlet strip that is set under the base. The fan is controlled by a switch and pot that are built into the base.

This basic design of 4 adjustable walls with a fog source on the bottom and a fan on top is very common among tornado demonstration machines. A similar device was patented in 1971 by William E. Morison and Carl T. Laybold. Currently there are many examples of variations on this design on display on the internet. Some major variations include a cylindrical instead of square shape, the inclusion of lighting effects to make the tornado more visible and different methods of fog generation.



United States Patent [11] **3,589,044**

[72] Inventors **William E. Morrison; Carl T. Laybold, both of Indianapolis, Ind.**
[21] Appl. No. **790,958**
[22] Filed **Jan. 14, 1969**
[45] Patented **June 29, 1971**
[73] Assignee **Jenn-Air Corporation Indianapolis, Ind.**

[54] **TORNADO DEVICE**
7 Claims, 7 Drawing Figs.
[52] **U.S. Cl.** **40/106.22, 35/49**
[51] **Int. Cl.** **G09f 13/24**
[50] **Field of Search** 40/126, 106.21, 106.22; 35/10, 49; 73/147

[56] **References Cited**

UNITED STATES PATENTS

1,221,494	4/1917	Wiley	40/106.25
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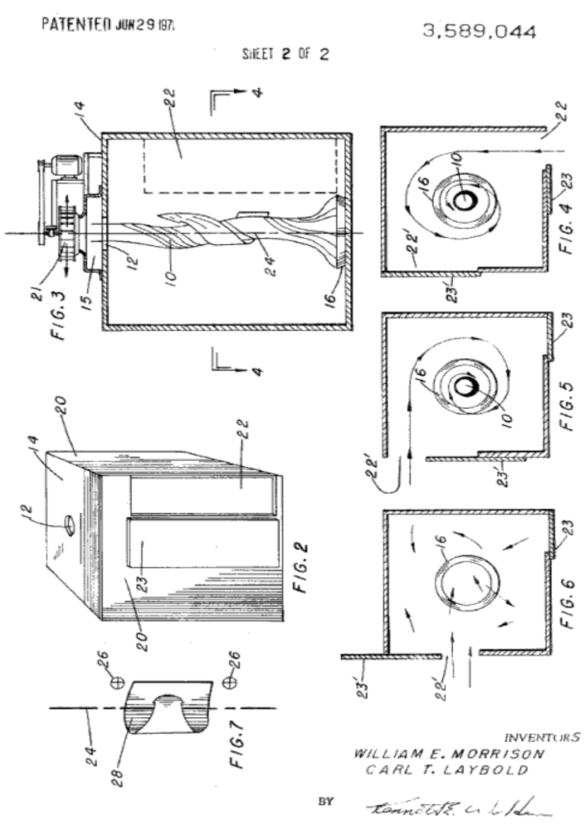
Primary Examiner—Robert W. Michell
Assistant Examiner—Wenceslao J. Contreras
Attorney—Kenneth E. Walden

ABSTRACT: Air moving apparatus arranged and operated as disclosed herein is capable of creating a visible tornadolike phenomenon for display, observation and study.

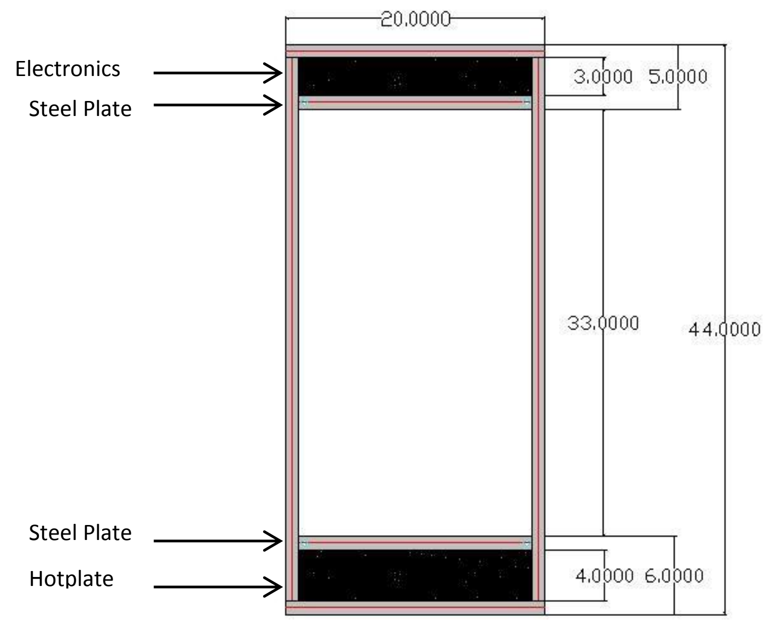


Requirements:

1) Case
   a) Size
      i) The machine will need to be more compact then his old machine. We will do this by shrinking down the size of the case and making it slightly higher to still get a presentable tornado.
      ii) The final dimensions of the case will be 20"x20" and 44" tall.
   b) Material
      i) The framing of the case will be made out of aluminum to give us the strength the case need to hold all the electronics and other equipment. It will also reduce the weight of case compared to making it out of steel. The aluminum will also make it look clean and professional.
      ii) The facing will be made of plastic to enclose all the parts. It will give it a professional finish that isn't going to be expensive and will be easier to work with then metal.
      iii) The sheet that the hot plate and electronics are mounted to will be made of metal. This will give the strength needed to hold the equipment without the sheet flexing. The sheet above the hot plate will also be metal, so it cannot be burned by the heat of the hot plate.
      iv) The walls will be made out of clear polycarbonate sheet which will give us a sturdy and clean looking wall.
2) Functionality
   a) Adjustable walls
      i) We designed the device so that the walls can be rotated by a group of stepper motors. Through this control we are able to both reverse the direction and adjust the size of the tornado.
   b) Fan control
      i) Using PWM and the PIC microcontroller we will be able to control the speed of the fan. Using this control we will be able to adjust the size and shape of the tornado.
      ii) By using a dual axial fan we can operate the device with a fan spinning in either direction. Controlling which fan is running is done by the PIC.
   c) Central command panel
      i) Through controlling most of the functions of the device though a PIC microcontroller we are able to control the fan, walls and lights from one location on the top of the device. If possible we will find an appropriate relay to control the hotplate from the top of the device. We will locate all of these controls on one panel on the top of the device.

3) Electronic Effects
   a) Lightning effects
      i) By using a combination of different LED's we can make a flashing effect to mimic lightning and show the different directions that lightning flows during a storm. For the final device we will incorporate the LED's more seamlessly into the device
   b) Demonstration mode
      i) The final device will contain a control which will allow the device to run by itself. This mode will include all of the functions that are controlled by the PIC.

<u>Description of our Case:</u>



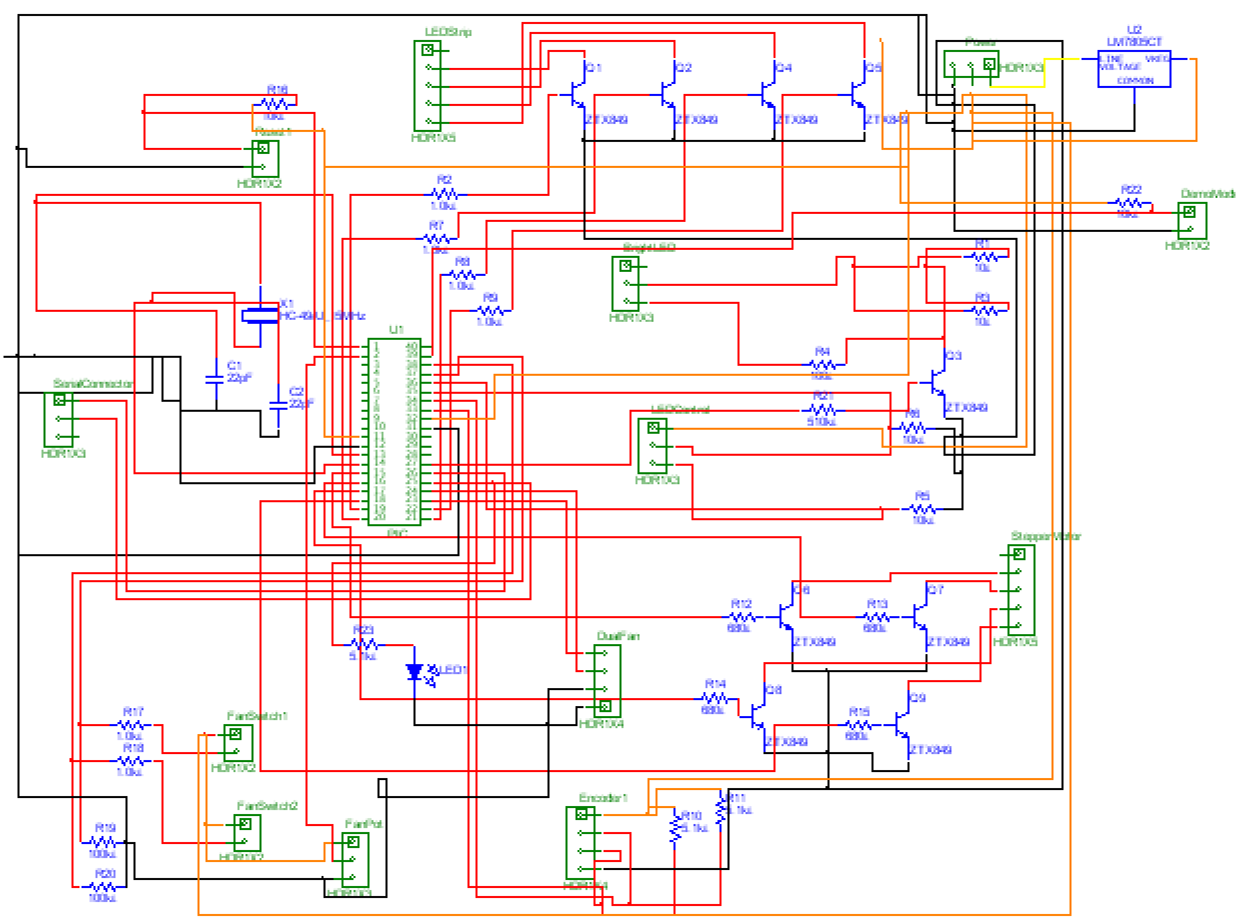
The case is made out of aluminum, steel, and HDPE plastic. These materials were picked because of the properties that they were able to provide. The aluminum is 80/20 modular aluminum frame. It is cut to the desired length and then connected to each other by connectors that were made for the frames. The aluminum frame gives us a rigid and attractive frame that is also lightweight. In the above picture the black is the HDPE plastic. The plastic closes off the electronics and hot plate, but also makes it more attractive. It also provides us with enough heat resistance in the bottom to withstand the temperature that the hotplate can generate. There are also steel plates in the top and bottom of the case. They fit into the groves of the aluminum

frames. On the top the steel plates give us the strength needed to support the electronic that we have mounted in there. Also there will be a steel plate on the bottom because of the hotplate. The above picture is the schematics for what the case looks like. It is 44' tall and 20"x20" wide. At the bottom there are threads inside the aluminum frame that one can easily thread feet or casters into. Currently there are feet in there which give the case more stability and make it easier to level the device to many surfaces.

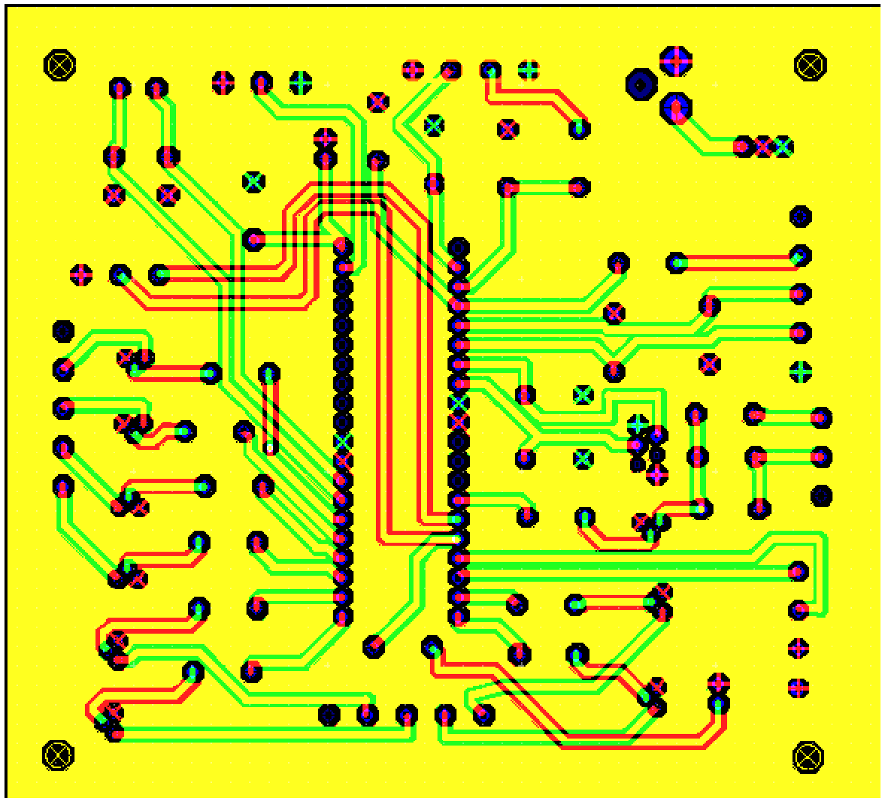
Circuit Schematics:

- Final PCB

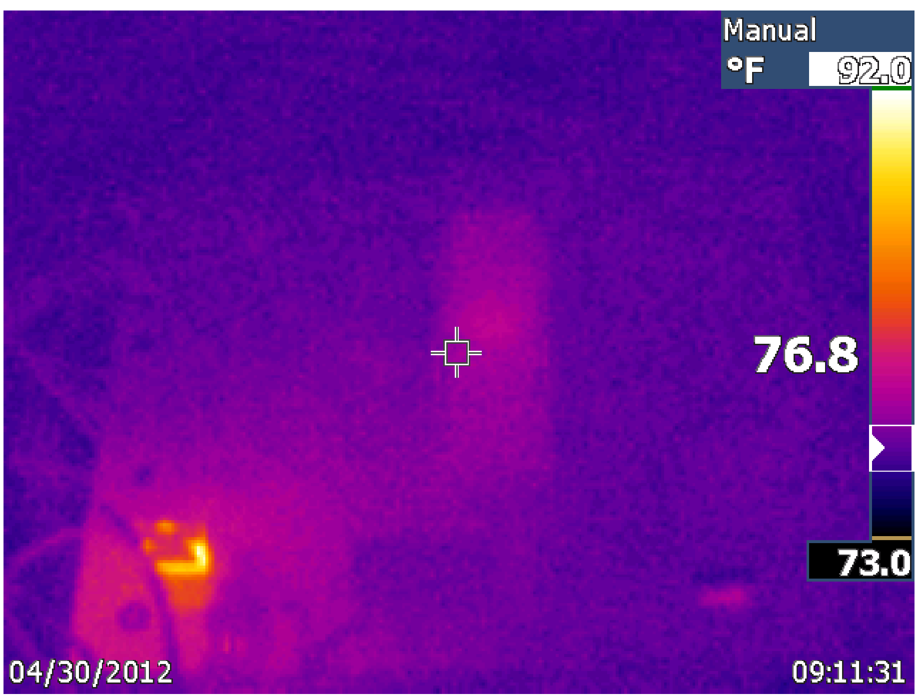
1. Circuit Diagram for Final PCB:



2. Final PCB Layout:

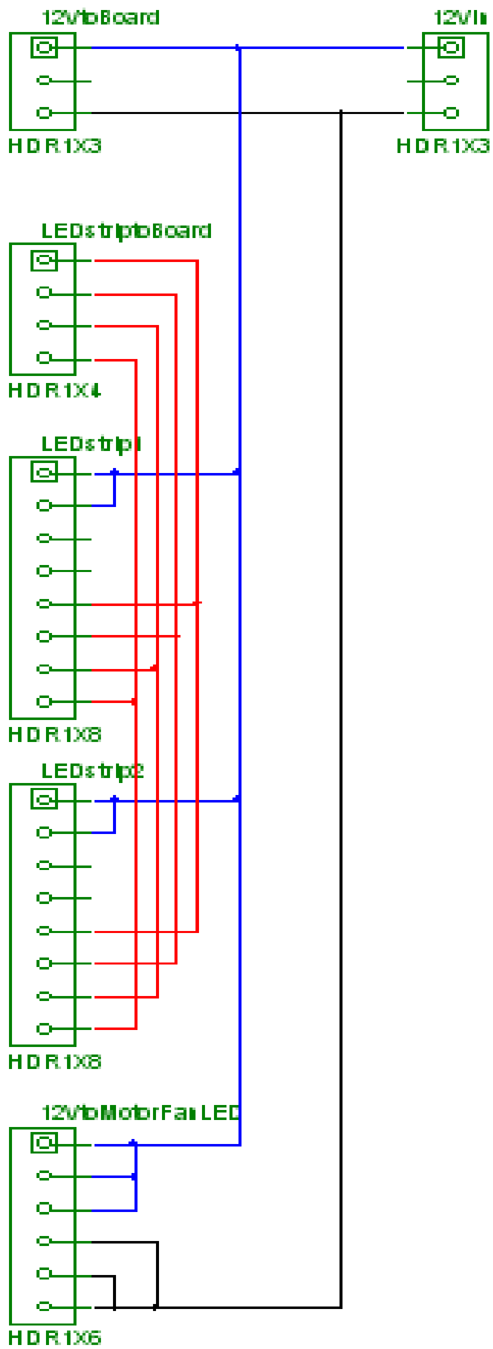


3. Final PCB thermal image:

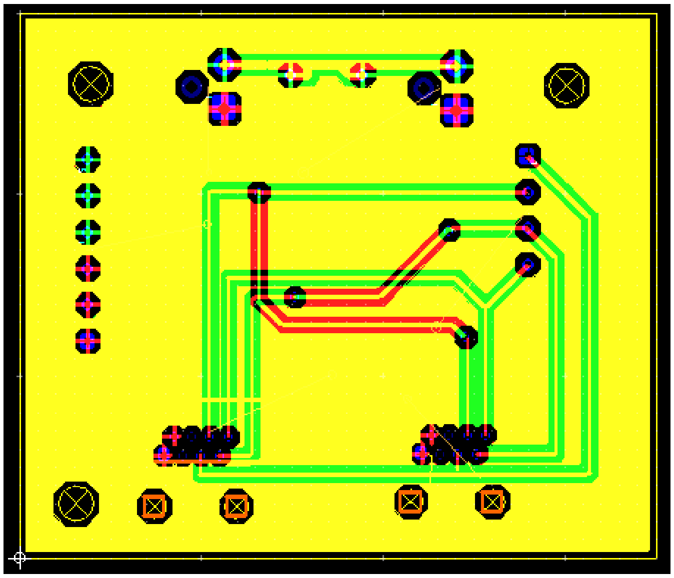


- **Power Management Board**

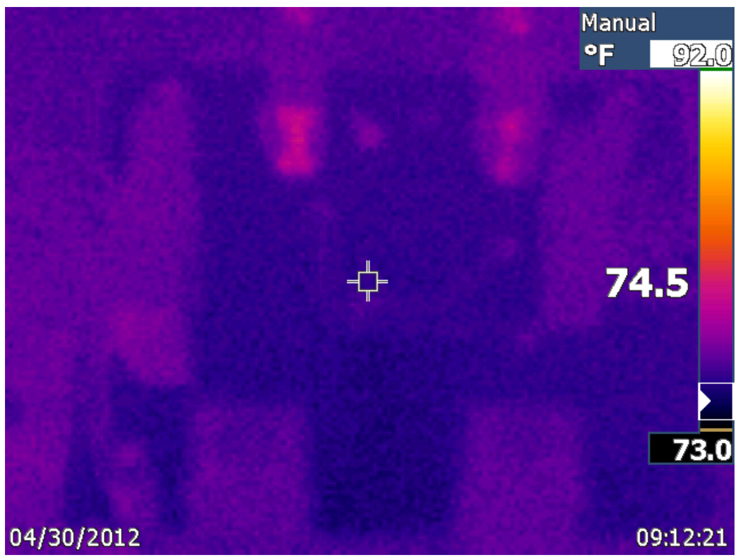
1. <u>Circuit Diagram for Power Management Board.</u>



2. <u>PCB Layout of Power Management Board.</u>

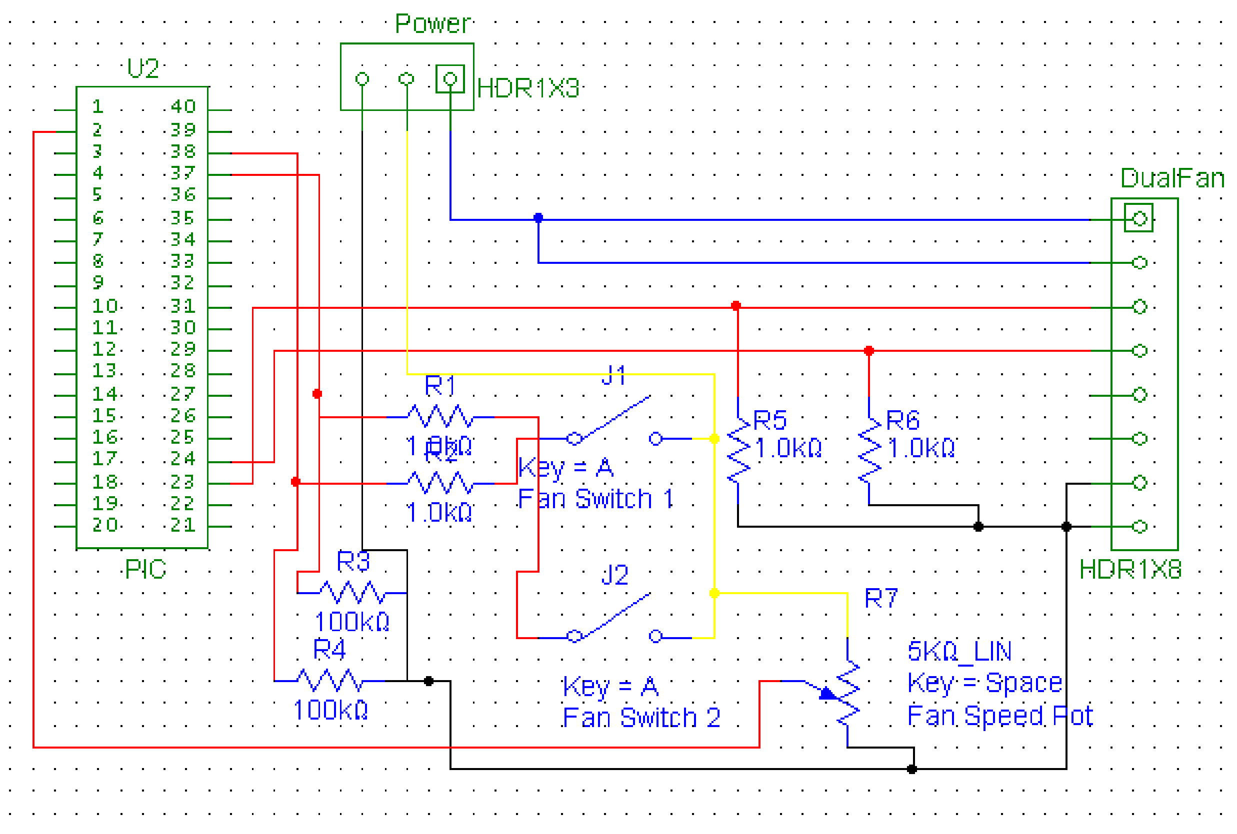


3. Thermal Image of Power Management Board.



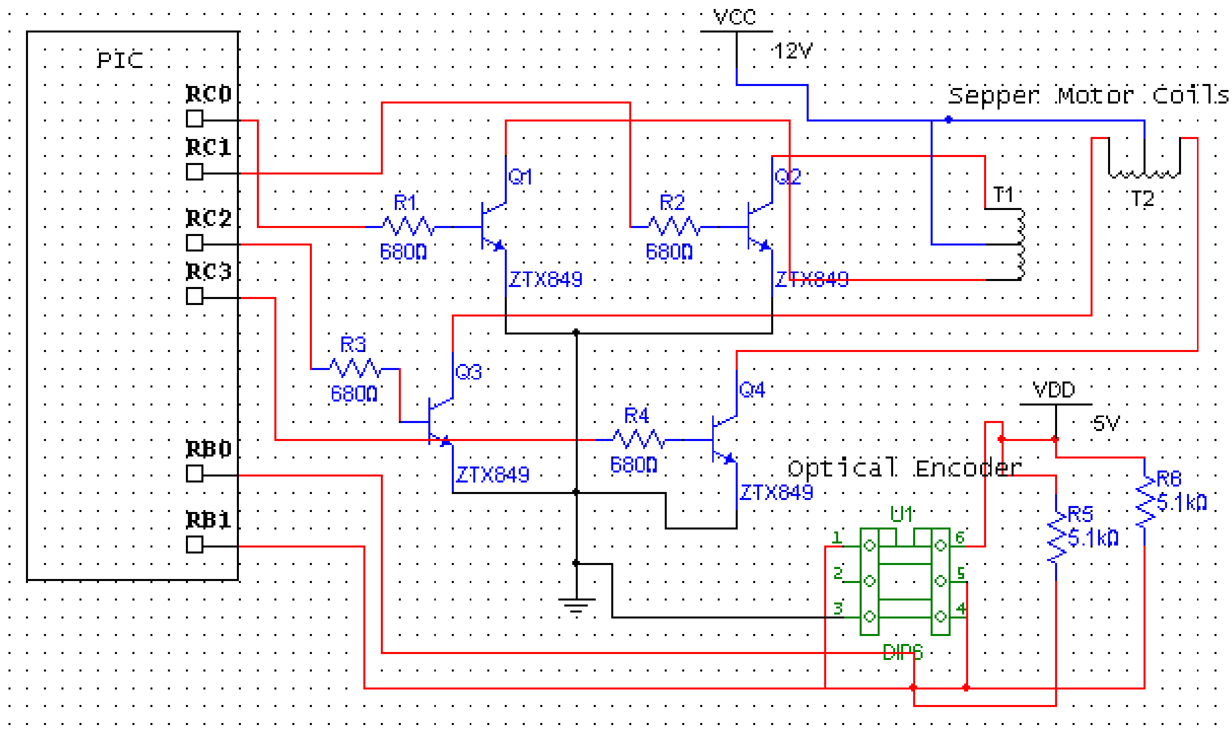
Shown above is the circuit diagram and layout of the secondary PCB we used for power management. This PCB is used to connect the +12V supply to the fan, motors, and the LEDs. This board also contains the connections between the 8 leads from the strip LEDs to the 4 BJTs that are used to control them on the other PCB.

<u>Fan Control Circuit:</u>



This Circuit diagram shows how we connected the dual axial fan to our electronics. The Fan has 8 leads. Two of the leads are connected directly to +12V and two are connected to Ground. Two of the leads are connected directly to the pic with pull up resistors. These leads carry the PWM signal to the fan. The final two leads of the fan act as a tachometer but go unused. To control the fan we use two switches and a 5k potentiometer. The two switches turn on and off the two fans and the potentiometer feeds a voltage between 0 and +5V to the A to D built into the PIC to control the speed of the fan.

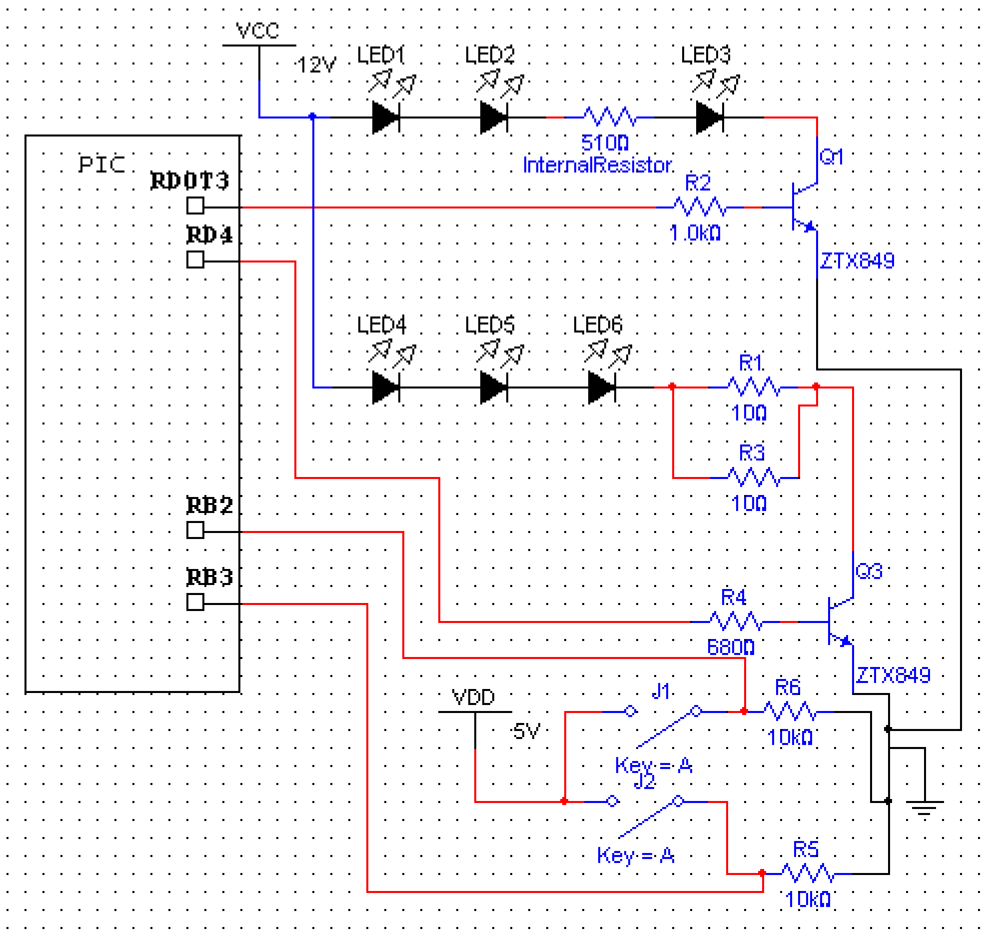
<u>Motor Control Circuit:</u>



This Circuit diagram shows how we connected the four stepper motors that we use to rotate the walls of the device. The diagram shows the two coils of one stepper motor. In the device the four motors are connected in parallel to what is shown on this diagram. The center of each coil in the motor is connected to +12V and each end of the coils are connected to the collector of a BJT. The base of each of these transistors is connected to the PIC though resistors and the emitters are grounded. When the pin on the PIC is in the low state no current flows from the base to emitter, this causes the current from collector to emitter to go to zero. When the pin on the PIC is brought high the rated current of .4 amps is allowed to flow through the coil.

The rotation of the motor is controlled though an optical encoder. This encoder is supplied by a +5V and ground lead. The two outputs of the encoder are fed directly to the PIC and are connected to a 5.1k pull up resistor.

LED Control Circuit:



This circuit diagram shows how the LEDs are connected. LEDs one, two and three are the strip LED that run along the side of the case. These LEDs are supplied at +12V and are grounded through a BJT acting as a switch controlled by the PIC. Each of the lengths of the strip LEDS are split up into 4 sections containing 6 LEDs. Every section is connected as shown above with each section being controlled by a different BJT. LEDs four, five and six are the ultra-bright LEDs that are mounted next to the fan. There are three groups of these three LEDs that are all supplied at +12V and grounded through a BJT controlled by the PIC. The LEDs are controlled by two switches connected to the pic a toggle to control whether the LEDs light randomly and a momentary switch to run the test of the LEDs.

Software:

Overview:

The software aspect of our project was created for the embedded PIC microcontroller used to control the device. The programing was done exclusively in C. The function of the program is to read in data supplied by the controls on the device, synthesize the data and then output the desired commands to the motors, fans and LEDs on our device.

Wall Control:

To rotate the walls of our device we needed the PIC to read in the data from the dial on the control panel and then to rotate the stepper motors based on this data and from internal data during the demonstration mode. To read in the data from the optical encoder we use for the dial the INT1 interrupt on the PIC is used. When rotation from the dial is detected a subroutine is called that rotates the wall. This subroutine is also used to operate the walls during the demonstration mode.

- INT1 routine:
  1. A rising or falling edge is detected on RB0
  2. The direction of rotation is chosen based on RB1 and if it was a rising or falling edge
  3. If chosen to be the forward direction the Rotate Wall Routine is called and signaled to rotate half a step in the forward direction
  4. If chosen to be the reverse direction the Rotate Wall Routine is called and signaled to rotate half a step in the reverse direction
  5. The interrupt is changed to look for the opposite of the rising or falling edge.
  6. The interrupt is cleared.
- Rotate Wall Routine (See Appendix A for flow chart):
  1. If signaled to rotate in the forward direction the value of the distance to rotate is used to set how many times the forward rotation loop is iterated
  2. If signaled to rotate in the backward direction the value of the distance to rotate is used to set how many times the backward rotation loop is iterated
  3. If the value of the forward rotation loop is positive PORTC is set to the appropriate value based on the motors cycle.

4. If one of the fans is turned on the PWM line is set to the appropriate value
5. The loop waits 20ms to allow the walls to rotate and then ends
6. If the value of the reverse rotation loop is positive PORTC is set to the appropriate value based on the motors cycle.
7. If one of the fans is turned on the PWM line is set to the appropriate value
8. The loop waits 20ms to allow the walls to rotate and then ends
9. PORTC is cleared to allow the walls to rotate freely
10. The routine ends.

Fan Control:

The fan uses the analog to digital converter, Timer1, and Timer1 compare interrupts on the PIC. The PIC gets a voltage input form the potentiometer. The PIC then translates that value into a digital value. That digital value then gets converted into a Timer1 compare value which sets the PWM value which controls the speed of the fans. It then waits until one of the two push buttons to get selected to determine which fan turns on and how fast by the PWM value.

- Fan Display Routine (See Appendix B for flow chart)::
  1. PIC receives A2D value and converts it over to Timer1 compare (CCPR1). Timer 1 interrupts is set for 13.1ms
  2. Continues until either push button is pushed.
     Yes
  3. Then Timer1=CCPR1.
  4. That signal then goes to the fan selected to set speed.
  5. Jumps back to number 1.

LED Control:

To control the LEDs on our device the PIC reads in the data from the control panel, synthesize the data and then controls the LEDs based on this. Based on whether the LED test is flagged or the random LED flashes are enabled a LED display routine is called. The time between random LED flashes is controlled by the TMR0 interrupt.

- <u>LED Display Routine (See Appendix C for flow chart):</u>
  1. If the LED test is not enabled one of three values is chosen to determine which display routine runs
  2. If signaled or if the LED test is enabled the ultra-bright LED is turned on for 150ms
  3. Waits 200ms
  4. If signaled or if the LED test is enabled the 1st, 2nd, 3rd and then 4th string LED are turned on in order for 50ms each
  5. Wait 200ms
  6. If signaled or if the LED test is enabled the 1st, 2nd, 3rd and then 4th string LED are turned on in reverse order for 50ms each
  7. Wait 200ms
  8. The LED routine flag is cleared
  9. End

Demonstration Mode:

The purpose of the demonstration mode is to operate the walls, fan and LEDs without input from the control panel. When enabled the mode runs through a set list of commands. This routine resets after the routine is turned off or after it runs for a certain amount of time. TMRO is used to call the routine every second when the mode is enabled.

- <u>Demonstration Routine (See Appendix D for flow Chart):</u>
  1. The Demo routine is called and given one integer value representing the location in the demonstration
  2. If there are commands listed at the location passed to the routine they are run
  3. If instructed to the Rotate Wall routine is run to rotate the walls a certain distance
  4. If listed the LED Display routine is run
  5. If listed which fan is operating is changed by the Set Motor routine
  6. If listed to the value of the speed of the fan is changed
  7. In the commands listed at the last location the location is reset to the beginning

Main Routine:

The purpose of the main routine is to read in most of the data from the control panel and then to take the appropriate actions. The inputs used during the main routine use pins RB2, RB3 and RB6. The main routine calls the LED routine and the demonstration routine. The routine also flashes an LED that is located on the board to show that the program is running correctly and sets the fan speed.

1. Increment the alert LED
2. If the alert LED is above 2750 (every 1 second) turn the LED on the PCB on or off.
3. If the LED routine is flagged run the LED display routine and then clear the flag
4. If the demonstration cycle is above 50 (every 1 second when demo mode is enabled) increment the demonstration mode location and then run the routine for the current location and then clear the cycle
5. If the demonstration mode is not enabled set the fan speed based on the voltage read by the A to D
6. If RB2 is high enable the random LED routine, if not disable it
7. If RB3 is high flag the LED test
8. If RB6 is high enable the demonstration mode
9. If RB6 is low turn off the fan disable the demonstration mode and then reset the demonstration location
10. Clear both RC4 and RC5 if RB4, RB5 and RB6 are all low
11. End the main routine.

Troubleshooting:

1) **The water does not heat up**
   a) To set desired temperature.
      i. Tip Machine over on its side.
      ii. Reach under to get to the dial on the hot plate.
      iii. Turn temperature up or down until you get your desired temperature.
   b) Doesn't Heat up.
      i. Make sure switch is in the "on" position.
      ii. If that doesn't work make sure electronics work.
         - If that doesn't work then you have a power problem wither behind the outlet in the case or the wall outlet.
      iii. Check solder connection on outlet of machine to make sure there connected.
      iv. If that doesn't a new hotplate is required.
2) **The case has been damaged**
   a) Aluminum Frames
      i. To take apart of the aluminum frames use an $\frac{5}{32}^{nd}$ allen wrench.
      ii. Connectors are located at joints where frame pieces meet up.
      iii. To replace any frame pieces order replacement from any 80/20 modular erectors set distributors (http://8020.net/) to get the desired length you need.
   b) Clear Polycarbonate Walls
      i. The current walls are clear polycarbonate sheets that are $\frac{1}{4}$ inch thick.
      ii. Sizes
         - Stationary walls: 6′′x 33.5′′
         - Moving walls: 7′′x 33.375′
      iii. New walls can be order at http://www.interstateplastics.com/ if new ones are required.
   c) Paneling
      i. Panels slide in and out of grove.
      ii. The thicknesses of panel are $\frac{3}{16}$".

iii. If new panel are needed they can also be order at http://www.interstateplastics.com/ .

3) **Nothing happens when the device is plugged in**

a) Carefully turn the device on its side and remove the cover that is in the corner of the bottom of the device.

b) Check that the light on the power supply turns on when the device is plugged in. If it does not light up check connections from the jack on the outside of the device to the power supply. If these connections are ok the power supply will need to be replaced.

c) If the light on the power supply turns on check the connections of the two wires that run from the corner of the case along the side.

d) Set the device back up vertically on its feet and remove one of the corner braces. Slide out the top piece of plastic to expose the electronics.

e) Make sure the device is powered and look for the LED that is on the green PCB. If it is flashing on and off steadily every second refer to sections 4, 5 and 6 of the troubleshooting guide. If the LED flashes erratically very fast or stays completely on refer to section 8. If the LED does not light continue to step f of this section.

f) Find the cord that comes out of the corner of the device and runs along the length. Unplug this cord from the PCB it is plugged in to and test that it is supplying 12V DC. If it is not at 12V recheck the power supply and then replace the cord.

g) Check the cord that runs between the two sockets on each of the PCBs when unplugged from the green PCB it should read 12V.

h) Check that the voltage on the green PCB is at 5V. An easy place to check this is the three position terminal next to the crystal, The voltage should read 5V between the two outside connections of this terminal.

i) If all of these voltages are read correctly refer to section 8.

4) **The walls do not turn correctly**

a) Check that the bottom and top of the case are free of debris. The four rotating walls should be able to rotate with very little resistance

b) Open the top of the case and look for the LED on the green PCB. If the LED is not flashing steadily every second refer to section 8 of this troubleshooting guide.

c) The black and white wires from the motors should be connected to the copper PCB in the terminal A.

d) The red, yellow, blue and brown wires should be connected to the terminal on the green PCB that is facing the fan. When looking from the direction of the control panel the wires should be connected in the order red, yellow, blue then brown from left to right

5) <u>The LED's do not flash correctly</u>

a) Open the top of the case and look for the LED on the green PCB. If the LED is not flashing steadily every second refer to section 8 of this troubleshooting guide.

b) If the LEDs connected next to the fan are not working correctly find the two leads that are connected to each of the LEDs. The black lead should be connected to the middle connection of the 3 position terminal facing the control panel. The red leads should be connected to copper PCB in the terminal A.

c) If the yellow string LEDs do not work correctly look for the two lengths of Cat 5 cable that run from the corners on top of the device. These two wires should be connected firmly to the two Jacks on the copper PCB. If the cables are connected securely to the copper PCB look for the red, yellow, black and white wires that run from the copper PCB to the green PCB. These wires should be connected to the terminals facing away from the control panel on the copper PCB and to the terminals facing left when looking from the control panel on the green PCB.

6) <u>The fan does not operate correctly</u>

a) Check that both fans are free of debris and spin freely.

b) Open the top of the case and look for the LED on the green PCB. If the LED is not flashing steadily every second refer to section 8 of this troubleshooting guide.

c) If one or both of the fans turn completely on when the device is powered look for the green and white wires coming from the fan. These wires should be connected to the terminal that is in the bottom left corner of the green PCB when facing from the direction of the control panel. The white and green wires should be connected to the 3^{rd} and 4^{th} connections on this terminal from left to right. Also 1k resistors should be connected from the 3^{rd} and 4^{th} terminal to the 2^{nd} terminal.

d) If either of the fans does not turn on find the red, orange, brown and black wires coming from the fan. The red and orange wires should be connected to the terminal A of the copper PCB to side that is fully pressed into the board. The brown and red wires should be connected to the raised connection of this terminal.

7) <u>The demonstration mode does not operate correctly</u>

a) Test that both of the fans work correctly by turning one fan on and then the other. If either of the fans does not work properly refer to section 6. After this make sure both of the fans are off when testing the demonstration mode.

b) Test that the walls rotate properly when the demonstration mode is off. If they do not work refer to section 4.

c) Test that the LEDs work properly when the demonstration mode is off. If they do not work refer to section 5.

d) After checking these three functions refer to section 8 for further help.

8) <u>Problem with the controller</u>

a) If you have not done so already open the top of the case and with a multi-meter check that the plug running from the copper PCB to the green PCB is at 12V DC when the device is plugged in. If it is not refer to section 3.

b) Check that the voltage on the green PCB is at 5V. An easy place to check this is the three position terminal next to the crystal; the voltage should read 5V between the two outside connections of this terminal.

c) Find the leads that come from the switches on the control panel. Test that all of these leads are connected securely to the green PCB.

d) While the device is plugged in briefly short the two terminals that are directly to the right of the microcontroller when looking from the direction of the control panel. This should reset the controller. If the LED on the board does not start to flash steadily every second continue on with this guide.

e) Check that the controller is firmly placed in its socket. There should be no give when the controller is pressed directly into the board.

f) Carefully replace the controller with the backup controller that is provided

g) Carefully remove the PCB from the device and check that all of the connections are soldered correctly

Problems encountered:

During the first semester of working on this project we had the idea of incorporating a second way to generate fog. We purchased a fog machine and tested it with our device. From testing we determined that the consistency and amount of fog generated by this machine did not work with this device. The fog generated by the machine is drawn quickly out of device before it has time to form into a tornado. Due to these problems and feedback from our client we decided to not incorporate the fog machine into the final device.

From the beginning of this project we knew that there would be problems making our case to be at the quality of the current case, but to stay under budget. Another factor that we had to consider was the weight of the final case. Throughout the first semester and into the beginning of the second semester we came up with different options for how we were going to build the case. In the end we decided on a hybrid of a couple of options we were considering. This final case was able to be built within our budget. The only problem we have with it is the weight that is slightly over the range that we were looking to be in.

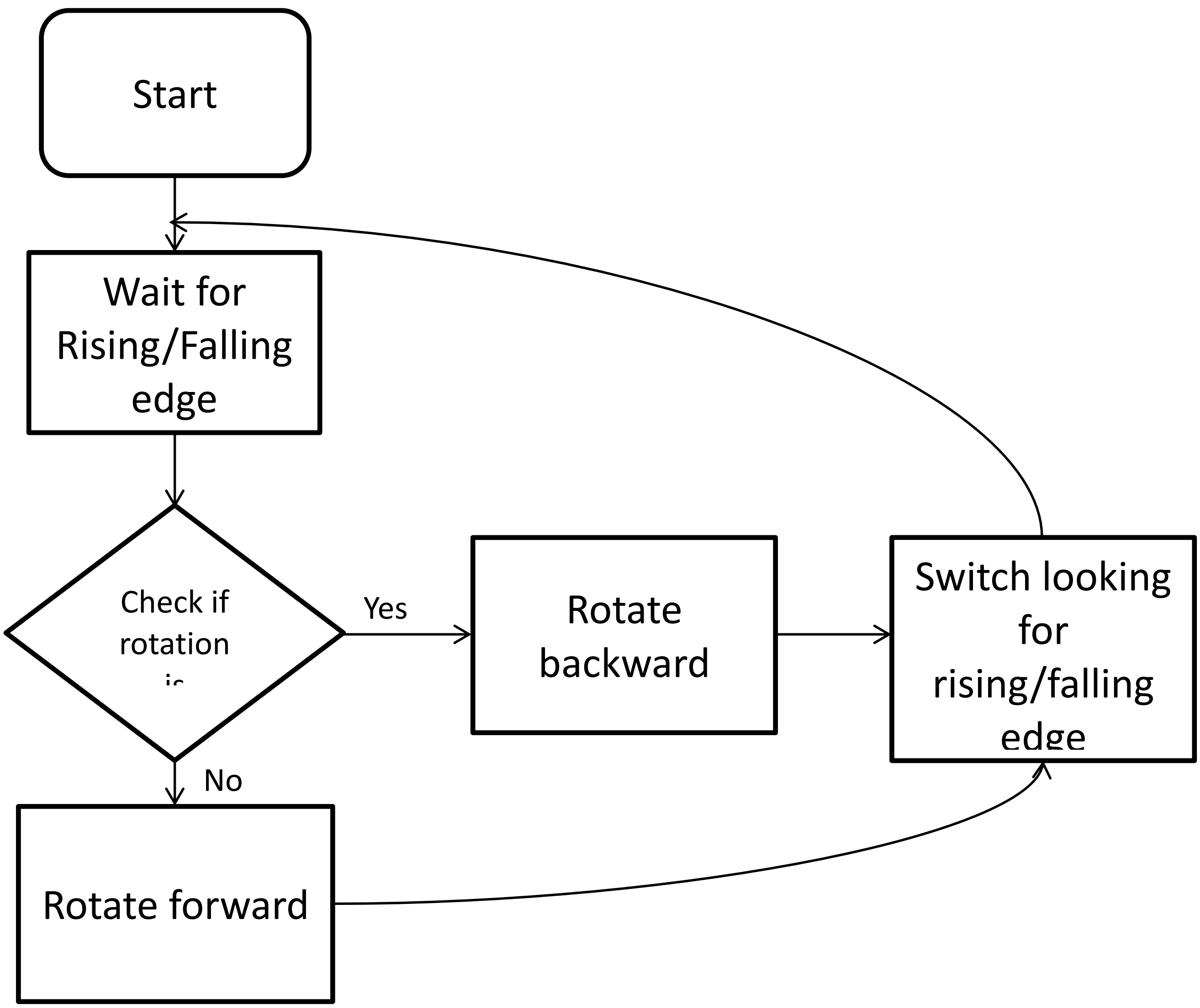
Another problem we encountered during the semester was having the walls rotate fast, but not so much that they would chatter back and forth when rotating. Until we had the final case built it was hard to determine how much resistance there would be to the walls rotating. After the final case was built it took a lot of fine tuning to adjust the code for the stepper motors to rotate fast enough but not so much to cause trouble with the walls rotating.

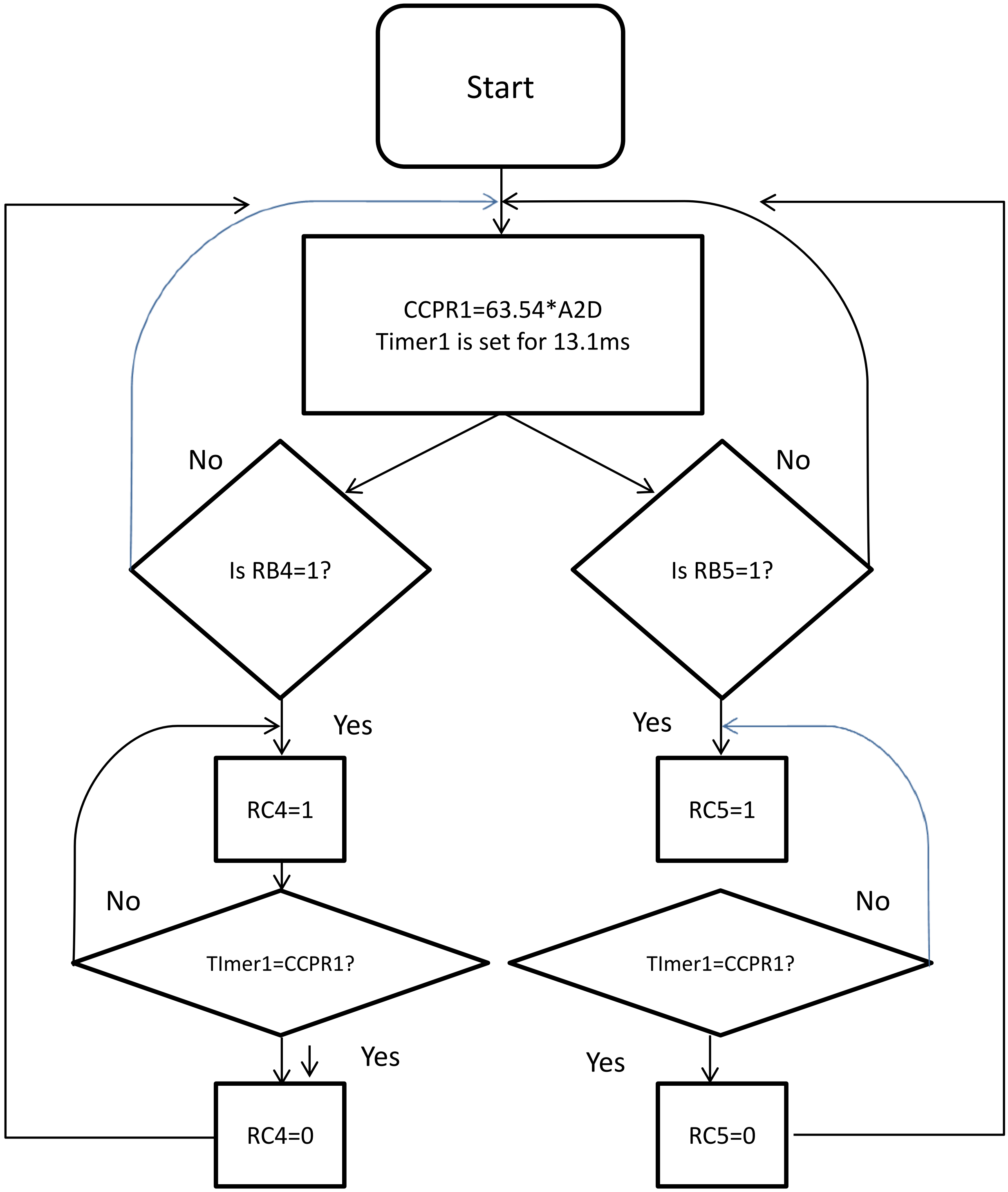
Final Thoughts:

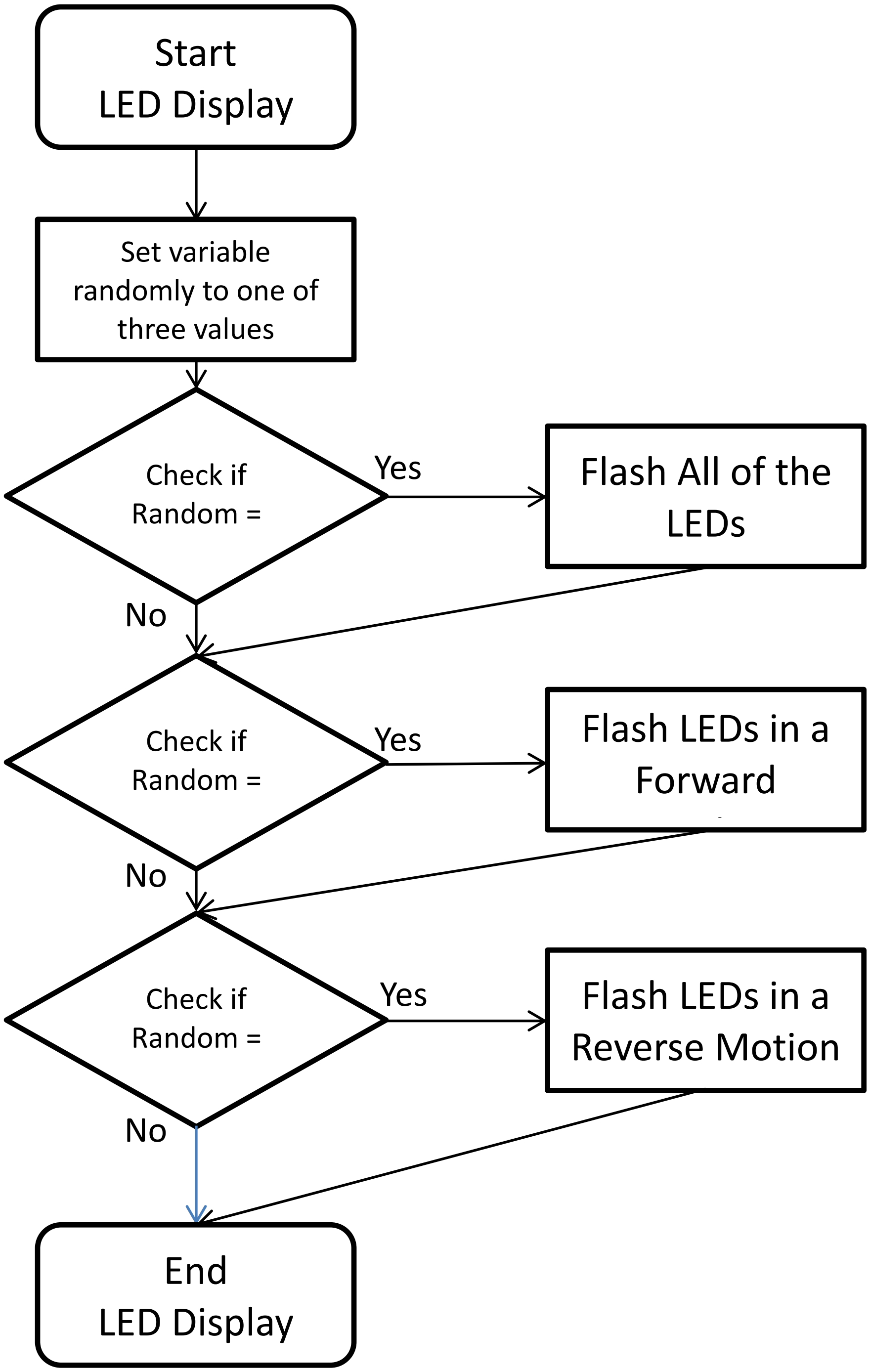
One idea we had during the design phase of this project we had was to add sound effects to the device to mimic thunder. When we lost one of our group members we decided to drop this idea. Adding this function to the device could be the topic of a future senior design project. Another thing that could be added would be to allow changes to the demonstration routine without having to adjust the code on the PIC.

This semester we successfully created a tornado simulation machine that Dr. Akyuz will use as tool in his work as an educator. We were able improve on the device Dr. Akuyz currently has

by making the device more portable and reliable. By incorporating electronic effects we added excitement to the device. We had many small and a couple of big problems that we had to overcome when building this device. The biggest of these was to make our case at a high quality while staying within the budget. Over the last two semesters we succeeded in designing, creating and testing a fun and easy to use educational device.


Start
Wait for Rising/Falling edge
Check if rotation is
Yes
No
Rotate backward
Switch looking for rising/falling edge
Rotate forward


Start
CCPR1=63.54*A2D
Timer1 is set for 13.1ms
No
Is RB4=1?
No
Is RB5=1?
Yes
Yes
RC4=1
RC5=1
No
TImer1=CCPR1?
No
TImer1=CCPR1?
Yes
Yes
RC4=0
RC5=0


Start
LED Display
Set variable randomly to one of three values
Check if Random =
Yes
Flash All of the LEDs
No
Check if Random =
Yes
Flash LEDs in a Forward
No
Check if Random =
Yes
Flash LEDs in a Reverse Motion
No
End
LED Display

Product	Company	Quantity	Retail Price per unit	Retail Total	Acquired
PCB board	Advance Circuits	1	50.85	50.85	50.85
12 V Fan	Digi-Key	1	45.59	45.59	45.59
Potentiometer	Digi-Key	1	11.4	11.4	11.4
encoder	Digi-Key	1	19.56	19.56	19.56
2 connectors	Digi-Key	2	1.33	2.66	2.66
ultrabright LED	Digi-Key	1	5.69	5.69	5.69
White LED	Digi-Key	4	1.86	7.44	7.44
Yellow LED	Digi-Key	4	1.14	4.56	4.56
NPN Transistors	Digi-Key	16	1.09	17.44	17.44
LED string	Digi-Key	8	1.29	10.32	10.32
120V to 12V power supply	Digi-Key	1	24.41	24.41	24.41
12V to 5V converter	Digi-Key	1	11.84	11.84	11.84
Push Button	Digi-Key	4	1.97	7.88	7.88
Black Push Button	Digi-Key	1	1.97	1.97	1.97
LED string	Digi-Key	2	9.1	18.2	18.2
Star LED's	Digi-Key	3	8.99	26.97	26.97
Case *	Frameexpert	1	350	350	114.06
2'x4' HDPE Sheet	Interstate Plastic	1	17.3	17.3	17.3
6"x33.5"x.236" Polycarb sheet	Interstate Plastic	4	17.52	70.08	70.08
7"x33.375"x.236" Polycarb sheet	Interstate Plastic	4	22.36	89.44	89.44
Shipping	Interstate Plastic			45.59	45.59
Stepper motors	Jameco	4	20.95	83.8	83.8
Hotplate	Jeff	1	23	23	0
Building Material	Misc.			60	0
Fog Machine	Musician's Friend	1	36.99	36.99	36.99
1 quart juice	Musician's Friend	1	7.99	7.99	7.99
18.5"x18.5" Steel Plates	Northern Plans Steel	2	25	50	0
Total				1100.97	732.03